Analysis of the Influence of Sponge Bus Bay Stop on Stormwater Runoff

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Abstract: The traditional bus bay stops are prone to ponding, with reduced waiting comfort, low traffic efficiency and easily damaged pavement structure. Given the problem, based on the sponge design of the bay stop in northern China, the rainstorm flood management model under the traditional and sponge modes is constructed, and the runoff condition of the bus stop is analyzed. The results show that the combination design of LID facilities, such as permeable pavement and the recessed green belt has a good control effect on rainwater runoff in the stop section. The larger the range of LID measures adopted in the stop section, the more pronounced the runoff control effect. The combined design of sponge facilities can effectively control rainwater runoff. However, with the increase in rainfall intensity, the control effect of sponge measures on rainwater runoff at the bus stop gradually decreases.

1. Introduction

According to the 2018 *Monitoring Report on the Density of Major Urban Road Networks in China*, the average road network density in urban built-up areas will increase to 8 km/km^2 by 2020. The proportion of roads in built-up areas will reach 15% [1]. The road system has always been an essential part of sponge city construction, but sponge city facilities should be set up based on local climate, hydrology and other conditions. Compared with southern cities, the northern cities have their unique geographical and climatic characteristics, making many practical road LID facilities in the south unsuitable for the northern cities. For example, there is less rain and more sand and dust, so the permeable pavement often used in the south is not practical in the north. The reasons are as follows: first, the temperature in winter in the north is low, and the average temperature in January is -10-0°C. Due to repeated freezing and thawing, the base of the permeable pavement is easy to damage due to frost heave. Second, the dust in northern cities is relatively large, so the gap of the permeable pavement is easily blocked by sand and mud, resulting in the embarrassing situation of impervious pavement. If the permeability of the permeable pavement is maintained, the daily maintenance will cost a lot. Liu Y N (2020) pointed out that cleaning the permeable pavement 3 to 5 times a year is recommended in northern inland areas. The porous asphalt concrete needs to be cleaned professionally at about 1.2 yuan/m^2·times, while the cleaning cost of permeable bricks and permeable concrete is about 0.7 yuan/m^2·times. At the same time, in the process of reconstruction, a large number of labour costs and machinery costs would be produced, and the construction will cause traffic congestion, increase noise and air pollution and other social impacts. Therefore, porous pavement reconstruction is challenging to implement in the northern region of an extensive road.

The bus stop links the public transport system and the road system. The bus bay stop is convenient for buses to stop, which improves the efficiency of road traffic to a certain extent, so it has been widely used. On rainfall days, the bay stop is located at the lowest place of the cross-section of the road and lacks separate drainage design guidance, and this leads to the following situation:

- Water accumulation in the bus stop area.
- Transit efficiency is reduced.
- It is easy to produce rain splash in bus transit.
- Poor passenger waiting experience.

At the same time, due to the frequent starting and braking of buses, it is easy to cause road fatigue damage and affect the quality of bus and road traffic service. Presently, domestic and foreign research on ground bus stops mainly focuses on geometric design, capacity analysis, delay, service quality, etc. This study takes the outer bus bay stop in the northern region as the object and explores a grey-green coupling system suitable for constructing sponge cities in the north of China. On the one hand, it provides a refined sponge city construction scheme to alleviate the northern region's urban waterlogging and water shortage. On the other hand, it solves the actual situation that the bay stop area is easy to pond, improving the operation quality of the public transportation system and reducing the road surface water damage in the bus stop area.

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2. Sponge bus bay stop

2.1. Overview of the study area

The research area is located in Shenyang, and the stop is a bus bay stop set up along the non-partition zone. The cross slope of the motorway and bus parking area is 1.5%, and the slope direction is the non-separating belt. The cross slope of sidewalks and non-motorized lanes is 1.5%, and the sidewalks and non-motorized lanes are separated. The road width is 41 meters, and the main is a two-way four-lane road. The cross-section of the route includes 3m sidewalk + 2m green belt + 3.5m non-motorized lane+5m green belt + 14m main road motorway + 5m green belt (including 3m wide parking area) + 3.5m non-motorized lane + 2m green belt + 3m sidewalk. The composition of the bus bay stop consists of the bus bay stop area (3m wide and 35m long); stop station platform (width of 2m, length of 35m);25m stop deceleration zone, and 30m stop acceleration zone. This study is a section of 100 m, including the bus bay stop area.

2.2.Scheme design

The non-divide is used for sunken treatment, the sidewalk and non-motorized lane partition are also used for sunken treatment, and the overflow well is set in the sunken green space. The rainwater can be easily collected into the sunken green space. The bus parking area and non-motorized lane adopt permeable pavement. Change the slope of the non-motorized lane to the divider non-separation belt. The sidewalk adopts permeable pavement brick pavement. The layout of LID facilities of the traditional bus bay stops and sponge bus bay stops is shown in Table 1.

Table 1. Layout scheme of LID facilities in the bus bay stop

Scheme	Terminal road section facility layout			
	Bus stop area	Green belt	Foot walk	Bicycle lane
Plan 1	Non-permeable	Traditional green space	Non-permeable	Non-permeable
Plan 2	Permeable road surface	Sinking green space	Permeable pavement	Permeable road surface
Plan 3	Permeable road surface	Sinking green space	Non-permeable	Non-permeable

Note: Scheme 1 is designed for the traditional mode station; Scheme 2 and 3 are designed for the sponge mode station.

3. Rain flood model establishment

At present, there are dozens of urban rainwater models at home and abroad, among which the more typical ones are InfoWorks CS, MIKE-URBAN, SWMM, STORM, HSPF and so on [6]. Among them, SWMM (stormwater management model, rainstorm and flood management model) is perfecter than other models, and its applicability is more extensive. In recent years, scholars at home and abroad have done a lot of related research on the applicability of the SWMM model [7]. This paper used the SWMM rainstorm flood management model for simulation analysis.

3.1. Sub-catchment area division and regional generalization

As previously mentioned, the bus bay stop is the research object, and only consider the catchment within the red road line. After a comprehensive analysis, the study area was divided into eleven sub-catchments, four nodes, four pipe sections and one outlet. The sub-catchment model is shown in Figure 1. The area and other relevant parameters are shown in Table 2.

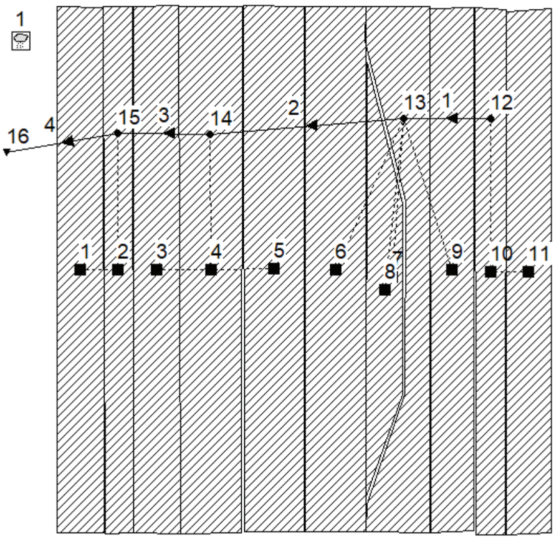


Figure 1. Model generalization

Note: 1,10 are sidewalks; 2,10 are green belts; 3,9 are non-motorized lanes; 3,7 are green belts; 8 is the bus stop area; 5,6 are non-motorized lanes.

Table 2. Division of sub-catchment areas

Sub-hui water area number	Area m^2	Zone length	Width
1	300	100	3
2	200	100	2
3	350	100	3.5
4	500	100	5
5	700	100	7
6	700	100	7
7	242.5	65	5
8	187.5	90	3
9	350	100	3.5
10	200	100	2
11	300	100	3

3.2. Model parameter setting

3.2.1. Rainfall parameters

The Chicago rain type was used to synthesize the designed rain type and simulate the rainfall process of 2h. The rainfall return period was 1,3,5,10, and 20 years. Shenyang city's latest rainstorm intensity calculation formula (1) was adopted to obtain the rainfall 30.306mm, 46.067mm, 53.396mm and 63.340mm, 73.284mm.

$$q=\frac{1052.768（1+1.09\log P）}{(t+5.9)^{0.667}} \quad (1)$$

In this formula: q=The average rainfall intensity; p=The designed rainfall recurrence period; t=The designed rainfall duration.

3.2.2. Hydrological and hydraulic parameters

In order to facilitate the construction and analysis of the model, this paper simplifies the drainage network of the region according to the specific planning and design of the docking station. The relevant attributes of each pipeline in the area are shown in Table 3.

Table 3. Overview of area pipeline

Pipe section number	Initial node	Terminal node	Length	Calibre
1	12	13	7	0.5
2	13	14	6	0.5
3	14	15	13	0.5
4	15	16	7	0.5

Combining the soil types and natural surface characteristics of the study area and referring to the SWMM user manual and related literature, the hydrological and hydraulic parameters such as Manning roughness coefficient, surface depression parameters, and Horton infiltration model parameters were calibrated[2,10]. The calibration results are shown in Table 4.

Table 4. Rate of hydrologic and hydraulic parameters

Parameter type	The parameter name	Rate value
MRC	Impermeable roughness rate	0.012
	Permeable roughness	0.13
	Plumbing roughness rate	0.013
SDSP	Opaque water storage volume /mm	2
	Water depression storage /mm	7
	The proportion of impervious zone without depression /%	25
HUMP	Maximum permeability/$mm\cdot h^{-1}$	25
	Minimum impermeability/$mm\cdot h^{-1}$	1.02
	Discount factor /h^{-1}	4
	Distraction coefficient /d	7

Note: MRC=Manning roughness coefficient; SDSP=Surface depression storage parameters; HUMP=Horton, infiltration model parameters

3.2.3. LID parameters

The LID facilities in this paper are mainly composed of sunken green belts, permeable brick paving and permeable pavement. According to the SWMM model manual and related literature, the LID parameters in the model are valued [9]. The set parameter values are shown in Table 5.

Table 5. The LID parameter is selected

Project		LID measure		
		Sinking green space	Permeable pavement	Permeable road surface
Superficial layer	Storage depth /mm	100	2	2
	Vegetation coverage%	0.17	0	0
	Manning n value	0.15	0.011	0.014
	Surface slope%	1.5	1.5	1.5
Soil layer (permeable pavement layer)	Thickness/mm	500	100	150
	Porosity%	0.502	0.2	0.25
	Water production capacity %/ pavement layer is the impermeable surface fraction	0.170	0	0
	Flight point %/ pavement layer is permeability/$mm\cdot h^{-1}$	0.078	360	200
	Water conductivity /$mm\cdot h^{-1}$ pavement layer is the blocking factor	14.4	0	0
	Water diversion slope	9	-	-
	suction head /mm	98.92	-	-
Aqueous stratum	Altitude /mm	100	100	300
	Void ratio	0.15	0.15	0.15
	Water seepage rate/$mm\cdot h^{-1}$	1.02	1.02	0
	Closure factor	0	0	0
Closed conduit	Discharge coefficient	-	-	3.3
	Drainage index	-	-	0.5
	Offset height /mm	-	-	0

4. Analysis of the model results

4.1. Analysis of the overall runoff condition of the stopping station section

According to the above relevant data, the rain-flood conditions of the three schemes of the stop station under the rainfall return period of 1, 3, 5,10, and 20 years are simulated, respectively. The rain-flood control effect is shown in Table 6.

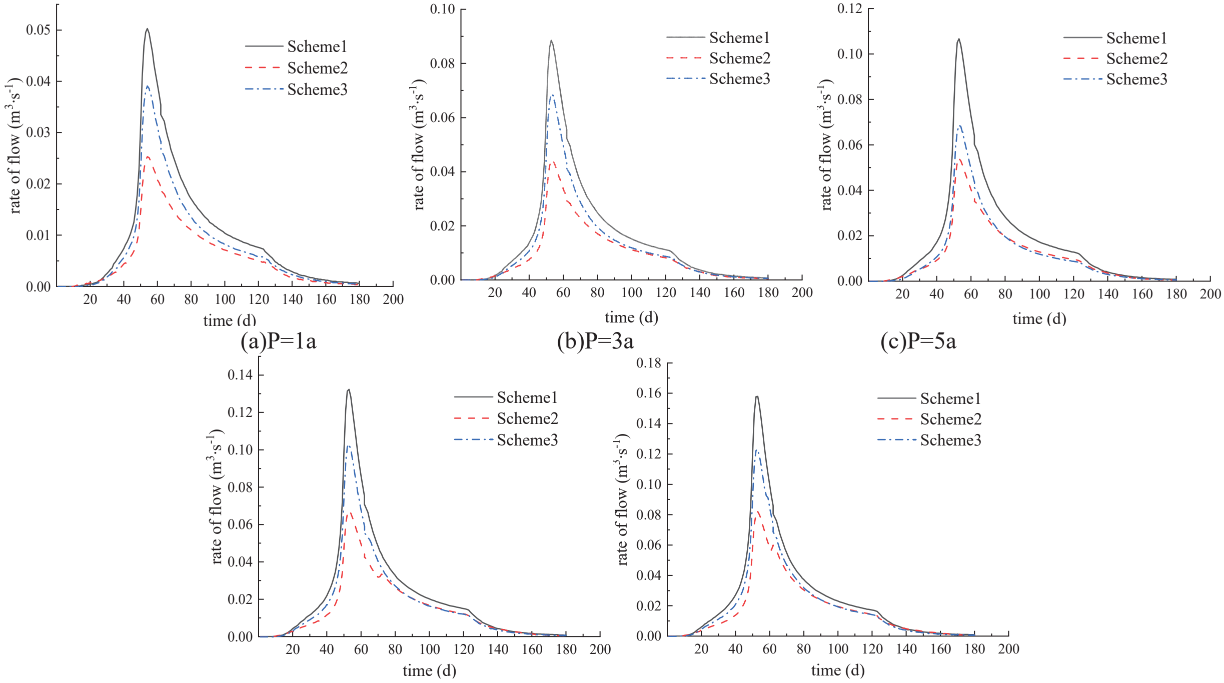
Table 6. Flood control effects of different schemes

Metric		Rainfall reproduction period				
		P=1	P=3	P=5	P=10	P=20
Total rainfall rate/mm		30.306	46.067	53.395	63.340	73.284
Yielding flow /mm	Plan 1	26.488	42.192	49.503	59.429	69.359
	Plan 2	15.614	25.706	30.477	38.568	46.770
	Plan 3	20.709	32.957	38.720	47.338	56.424
Total runoff control rate /%	Plan 1	12.60	8.41	7.29	6.17	5.36
	Plan 2	48.48	44.2	42.92	39.11	36.18
	Plan 3	31.67	28.46	27.48	25.26	23.01

The results show that under different rainfall return periods, compared with the traditional construction mode (Scheme 1), the total runoff of the stop station section of the sponge development mode (scheme 2) is reduced by 41.05%, 39.07%, 38.43%, 35.10% and 32.57% respectively. The total runoff control rate is 48.48%, 44.20%, 42.92%, 39.11% and 36.18%, respectively. The total runoff of the sponge development mode (Scheme 3) was reduced by 21.82%, 21.89%, 21.78%, 20.35% and 18.65%, respectively, and the total runoff control rate reached 31.67%, 28.46%, 27.48%, 25.26% and 23.01%. Under the sponge development mode, the total runoff of the stop section of Scheme 2 is 17.11 % -24.60 % lower than that of Scheme 3. The results indicate that sponge docking stations can play a significant role in controlling the total runoff, and the runoff control effect is more apparent when sponge measures are taken respectively in bus-stopping areas, green belts, sidewalks and non-motorized lanes.

4.2. Analysis of runoff of docking section

Based on the above relevant data, the runoff of three different schemes under the two development modes of the station section under the rainfall return period of 1,3,5,10, and 20 years is simulated, respectively. The comparison of the total flow of the outlet under different return periods of the three schemes is shown in figure 2. The peak value, peak time and total flow of the outlet under different return periods of the three schemes are shown in Table 7.



(a)P=1a (b)P=3a (c)P=5a

(d)P =10a (e)P=20a

Figure 2. Comparison of the total flow rate of the water outlet

Table 7. Water outlet quantity of different schemes

Metric		Rainfall reproduction period				
		P=1	P=3	P=5	P=10	P=20
Peak size /$(m^3 \cdot s^{-1})$	Plan 1	0.051	0.089	0.107	0.133	0.159
	Plan 2	0.025	0.044	0.054	0.068	0.082
	Plan 3	0.039	0.069	0.083	0.103	0.124
Peak time	Plan 1	00:54	00:53	00:53	00:53	00:53
	Plan 2	00:54	00:53	00:53	00:53	00:53
	Plan 3	00:54	00:53	00:53	00:53	00:53
Total outflow/10^6L	Plan 1	0.106	0.169	0.198	0.238	0.278
	Plan 2	0.062	0.103	0.122	0.154	0.187
	Plan 3	0.083	0.132	0.155	0.190	0.226

The results show that under the 1,3,5,10, and 20-year rainfall return periods, compared with the traditional model, the peak flow of the outlet node of the second scheme is reduced by 50.98 %, 50.56 %, 49.53 %, 48.87 % and 48.43 % respectively. The third scheme is reduced by 50.98 %, 50.56 %, 49.53 %, 48.87 % and 48.43 %, respectively. The total outflow of the second scheme decreased by 41.51 %, 39.05 %, 38.38 %, 35.29 % and 32.13 %, respectively, and the third scheme decreased by 41.51 %, 39.05 %, 38.38 %, 35.29 % and 32.13 % respectively. Under the sponge development mode, the peak flow of the outlet of Scheme 2 is 33.87 % -35.90 % lower than that of Scheme 3, and the total outflow is reduced by 17.26 % -25.30 %. The peak time of outlet flow under sponge development mode is not much different from that under traditional development mode.

5. Summary and conclusions

1. This paper puts forward the sponge optimization design method of the bus bay stop: increasing the stop section's permeable area, changing the stop road's drainage mode, and giving the specific sponge transformation scheme of the traditional bus bay stop.

2. LID measures to the research area design can effectively control the surface runoff when the rainfall increases from 1 year to 20 years, two docking models of rainfall runoff. Still, the sponge development mode of runoff reduction rate is significantly higher than the traditional development mode. Runoff reduction under low recovery conditions is more substantial than the high recovery period.

3. Through the comparative analysis of the total amount of the system runoff, the peak flow of the outlet and the total amount of the outflow under two different development conditions, the sponge docking station has a noticeable reduction effect on the rainwater runoff. But as the rainfall intensity increases, the runoff reduction rate will decrease accordingly. The above conclusion illustrates that the impact of rainwater runoff control will reduce with increased rainfall intensity.

4. According to the comparison of the outlet flow simulation results of the model, the peak water outlet flow occurrence time of the sponge development mode is not much different from the traditional development mode under different rainfall recurrence periods. The research area can be expanded to take sponge measures to reflect the apparent effect of peak flow delay. This paper only discusses the section of the bus bay stop, so it is not considered.

Acknowledgments

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